THE MAINTENANCE OF FERTILITY.

FIELD EXPERIMENTS WITH FERTILIZERS ON CEREAL CROPS. LIME AND CLOVER. THE HOME MIXING OF FERTILIZERS.

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THE MAINTENANCE OF FERTILITY.

FIELD EXPERIMENTS WITH FERTILIZERS.

BY C. E. THORNE.

Experiments in the application of fertilizers to the cereal crops were begun at the Station in 1893 and are still in progress. In one of these tests fertilizers are used on corn, oats, wheat, clover and timothy, grown in rotation. In 1895 a duplicate of this rotation experiment was begun at the North-eastern test farm, at Strongsville, Cuyahoga county.

The full plan of these experiments is given in Bulletin 110, and a summary of the results, up to 1900, is published in Bulletin 124. Briefly stated, the first 13 plots in the rotation work are devoted to a study of the effect of carriers of phosphorus, potassium and nitrogen respectively, on crops grown on the soils on which these tests are located. Then follow experiments with different quantities of fertilizers, with different carriers of nitrogen and phosphorus, and with barnyard manure.

The present discussion will be limited to questions relating to the economical production of crops by the use of commercial fertilizers, the consideration of the full results of the test being reserved for future publication.

In this rotation experiment all three of the cereal crops receive dressings of fertilizers except on four plots, on one of which the oats crop is passed without any fertilizer, on one both oats and corn are so passed, and two plots are dressed with barnyard manure, this being applied only to the corn and wheat. The wheat crop is followed by two years of clover and timothy, which crops receive no further addition of fertilizer or manure.

TABLE I.—FERTILIZERS APPLIED IN POUNDS PER ACRE.

Plot No.	On corn.			On oats.			On wheat.			
	Acid phosphate	Muriate of potash	Nitrate of soda	Acid phosphate	Muriate of potash	Nitrate of soda	Acid phosphate	Muriate of potash	Dried blood	Nitrate of soda
1	..	..	....	..	..	....	....	....	..	....
2	80	.	....	80	..	....	160	....	..	....
3	..	80	....	..	80	....	....	100	..	....
4	..	..	....	..	..	....	....	....	..	....
5	..	..	160	..	..	160	....	....	50	120
6	80	..	160	80	..	160	160	....	50	120
7	..	..	....	..	..	....	....	....	..	....
8	80	80	....	80	80	....	160	100	..	....
9	..	80	160	..	80	160	....	100	50	120
10	..	..	....	..	..	....	....	....	..	....
11	80	80	160	80	80	160	160	100	50	120
12	80	80	240	80	80	240	160	100	50	200
13	..	..	....	..	..	....	....	....	..	....
14	80	80	160	..	..	....	160	100	50	120
15	..	..	....	..	..	....	160	100	50	120
16	..	..	....	..	..	....	....	....	..	....
18	Manure, 8 tons.			..	..	....	Manure, 8 tons.			....
19	..	..	..	..	..	....	....	....	....	....
20	Manure, 4 tons.			..	..	....	Manure, 4 tons			....

In these experiments every third plot, beginning with plot 1, is left continuously unfertilized, and the increase for the fertilized plots is calculated on the assumption that variations in the soil are progressive, and that if plots 1 and 4, unfertilized, should yield 30 and 33 bushels per acre, respectively, the unaided yields of plots 2 and 3 would have been 31 and 32 bushels. The average yield of all the unfertilized plots is only used as an index to the character of the soil or season.

In distributing the fertilizers, the corn and oats crops receive the same kinds and quantities of fertilizing material, except on plot 14 and the two manured plots, while the wheat crop receives 160 pounds of acid phosphate instead of 80 pounds, 100 pounds of muriate of potash instead of 80 pounds, and 50 pounds of dried blood and 120 pounds of nitrate of soda, the dried blood being applied at seeding time in the fall and the nitrate of soda sown broadcast in April, the whole dressing being calculated to carry the same quantity of nitrogen as 160 pounds of nitrate of soda.

These quantities of the fertilizing materials named carry phosphorus and potassium in approximately the same ratio to each other in which they are found in the general average of the crops grown in the test, while nitrogen is carried in about one-third that ratio; the assumption, in planning the test, being that the clover would secure from the soil and atmosphere, not only its own supply of nitrogen, but a surplus which would partially meet the needs of the other crops.

Table I gives the plan of fertilizing, which is the same for both the Wooster and the Strongsville tests; Table II gives the average yield per acre for each crop, over the entire period of the test, and Table III gives the average increase per acre produced by the different fertilizers.

Taking Table III and considering the three plots on which the different fertilizing constituents have been applied separately, we see that acid phosphate, the carrier of phosphorus, has produced very much the largest increase, and that this increase is somewhat greater in the aggregate at Strongsville than at Wooster. The effect of potassium is small at both places. That of nitrogen is insignificant at Strongsville, but second to that of phosphorus at Wooster. Taking the next three plots, on which these constituents are applied in combinations of two, we see that in both tests the combination of phosphorus and nitrogen, as applied to plot 6, produces the greatest effect, and that this effect is greater at Wooster than at Strongsville.

Considering now plots 11 and 12, which receive all three of the constituents, we find that the Wooster test shows very much the larger increase. In both these tests it will be seen that the increase from the combination of the carriers of nitrogen and phosphorus on plot 6 is considerably greater than that from the same materials used in the same quantities, but separately, on plots 2 and 5, and again that the addition, on plot 11, of a carrier of potassium to the fertilizers used on plot 6, gives an additional increase much larger than that found from the same quantity of potassium in the same carrier, when used either alone on plot 3, or in combination with phosphorus on plot 8, or with nitrogen on plot 9. It is very evident that for these soils some carrier of phosphorus is the first fertilizing agent needed, but that before this element can accomplish its full effect it must be associated with materials carrying both nitrogen and potassium.

TABLE II.—AVERAGE YIELD PER ACRE.

Plot No.	Corn 9-year average		Oats 9-year average		Wheat 9-year average		Hay 7-year average	
	Ear-corn	Stover	Grain	Straw	Grain	Straw	1st year (Clover)	2nd year (Timothy)
	Bushels.	Pounds.	Bushels.	Pounds.	Bushels.	Pounds.	Pounds.	Pounds.
WOOSTER.								
1	34.92	1673	32.19	1214	7.51	827	1606	2743
2	41.40	1779	39.44	1414	14.73	1540	2070	2867
3	38.74	1839	33.69	1221	9.52	1020	1903	3004
4	34.60	1650	31.55	1201	8.30	892	1874	2771
5	38.65	1758	35.39	1317	9.66	1072	2083	3017
6	48.02	1953	45.08	1674	19.33	2065	2646	3149
7	35.06	1598	30.87	1131	8 15	894	1716	2596
8	45.10	1994	40.50	1524	17 07	1663	2296	2826
9	37.87	1789	34.00	1288	10.00	1048	2096	2773
10	33.08	1520	30.37	1086	7.98	828	1759	2516
11	48.59	2054	48.60	1918	22.41	2417	2699	3220
12	50.00	2108	49.10	2094	23.41	2457	2824	3044
13	34.06	1634	31.13	1187	8.04	834	1737	2490
14	47.85	2135	37.77	1503	20.35	2226	2597	3069
15	37.51	1780	30.78	1128	19.37	2075	2171	2779
16	31.52	1641	28.81	1077	7.05	730	1581	2446
18	48.41	2232	39.19	1512	14.76	1723	2923	3477
19	35.39	1717	29.77	1089	7.42	758	1726	2534
20	44.19	2062	34.48	1304	12.15	1436	2474	3193
STRONGSVILLE.								
1	22.42	1418	31.50	1305	4.32	365	1317	2793
2	29.22	1492	41.35	1658	11.37	1140	2200	2767
3	21.73	1403	32.91	1330	4.52	368	1268	2253
4	20.36	1339	31.27	1282	5.22	485	1092	2053
5	21.78	1409	32.75	1434	4.91	452	1443	1993
6	30.61	1527	45.85	1831	14.56	1375	2130	2290
7	22.89	1447	33.93	1367	5.75	516	1580	2040
8	30.28	1491	45.25	1853	12.15	1080	2150	2920
9	24.58	1496	36.86	1653	7.10	673	1685	2567
10	24.30	1455	35.84	1452	5.68	517	1497	2867
11	35.51	1832	48.75	2077	15.14	1361	2339	3453
12	33.54	1801	48.73	1981	18.48	1785	2187	3187
13	25.20	1491	36.64	1589	5.94	539	1518	2660
14	33.09	1756	41.99	1733	16.91	1562	2327	3093
15	26.16	1528	35.39	1484	15.37	1386	2028	2637
16	27.00	1627	35.32	1402	6.63	577	1455	2467
18	36.59	1868	40.35	1709	13.58	1295	2267	3013
19	24.92	1634	32.52	1288	4.17	303	1332	2347
20	32.98	1800	35.98	1536	10.26	922	2060	3047

TABLE III.—AVERAGE INCREASE PER ACRE.

Plot No.	Corn. Ear-corn	Corn. Stover	Oats. Grain	Oats. Straw	Wheat. Grain	Wheat. Straw	Hay. 1st year	Hay. 2nd year	Total weight of increase
	Bushels.	Pounds.	Bushels.	Pounds.	Bushels.	Pounds.	Pounds.	Pounds.	Pounds.
	WOOSTER.								
2	6.59	114	7.46	204	6.96	692	375	115	2618
3	4.03	182	1.93	15	1.48	152	118	242	1142
5	3.90	126	4.06	139	1.41	181	261	304	1499
6	13.12	339	13.98	520	11.13	1172	877	494	5436
8	10.70	422	9.80	408	8.98	791	566	257	4045
9	4.13	244	3.46	187	1.97	198	351	232	1730
11	15.18	496	17.98	798	14.42	1587	947	713	7038
12	16.27	512	18.22	940	15.39	1624	1080	546	7347
14	14.64	499	7.41	351	12.64	1427	912	593	5802
15	6.90	168	2.94	140	11.98	1309	539	318	3770
18	14.59	541	8.77	440	7.46	974	1245	972	5921
20	10.14	388	5.08	228	4.79	683	817	747	4022
	STRONGSVILLE.								
2	7.48	100	9.64	361	6.75	735	958	220	3611
3	.67	37	1.56	40	—.40	—76	102	—47	129
5	.57	33	.57	125	—.49	—43	189	—56	277
6	8.56	115	12.80	492	8.99	870	713	246	3984
8	6.92	41	10.68	457	6.43	564	598	604	3476
9	.75	41	1.66	230	1.39	157	161	—25	753
11	10.91	366	12.63	579	9.37	836	834	655	5000
12	8.64	322	12.36	438	12.62	1254	676	458	4096
14	7.29	220	5.79	206	10.75	1010	829	498	4104
15	2.59	75	.56	115	8.99	821	552	106	2408
18	10.98	236	6.89	383	8.61	900	893	627	4547
20	7.10	154	2.36	151	5.04	510	667	602	2959

In the case of the Strongsville soil the need for phosphorus is even more pressing than at Wooster, but here the effect of both nitrogen and potassium is less marked than at Wooster. This difference in the responsiveness of these soils to fertilizers may be understood if we examine into their previous history. Both soils are of glacial drift origin, though in both cases the drift sheet is comparatively thin and is largely modified by the underlying rock, which is a more argillaceous shale in the case of the Strongsville soil than in that at Wooster, thus giving rise to a soil containing a considerably larger per cent. of clay. The difference in the soils which is the chief factor in producing the results observed, however, consists in the larger proportion of decaying vegetation found in the Strongsville soil, that soil having been in pasture some twenty years before the experiment began, whereas the Wooster soil had been in cultivation under tenant husbandry over the same period, and by exhaustive cropping had had its organic matter reduced to about 62 per cent. of that found in the other soil.*

These experiments show that it is possible to produce a large increase of crop by the use of fertilizers; but the important question to the farmer is whether this increase can be produced with economy. That is, whether the cost of the fertilizers may not be greater than the value of the increase. This question can only be satisfactorily answered by a consideration of the results obtained in the entire rotation. In Tables IV and V is therefore given the average annual value of the increase found from each crop during the entire period of the test, together with the average total value of the increase from all the crops in each rotation, with the total cost of fertilizers applied during a rotation and the net gain or loss found by deducting this cost from the value of the increase, estimating corn at one-third of a dollar per bushel, oats at 25 cents per bushel, wheat at two-thirds of a dollar per bushel, corn stover (fodder) at $3.00 per ton, straw at $2.00 per ton and mixed hay at $6.67 per ton. These prices may be lower than present values, but they do not differ materially from average values on the farm during the period over which this test was in progress.

Table V has been compiled to show the outcome of fertilizing the separate crops. It gives the cost of the different applications for each crop, and the profit or loss from such applications, as shown by the difference between this cost and the value of the increase, as given in Table IV; finally, the total average outcome for each 5-year rotation is given, the value of the residual increase found in the two hay crops being included with that of the cereal crops to which the fertilizers were applied in this final computation.

Taking the corn crop, the table shows that the small dressing of acid phosphate used on plot 2 has returned its cost nearly four times over at Wooster and more than that many times at Strongsville. When either nitrate of soda or muriate of potash has been added to the acid phosphate, as on plots 6 and 8, there has been a much larger increase of crop; but in the quantities in which these materials have been employed in this test, the additional cost of the fertilizers has been so great as to reduce the net profits per acre at Wooster and to convert it into loss at Strongsville. When both these materials have been added, as on plots 11, 12 and 14, there is further increase in yield, but the profit entirely disappears in both tests.

* Bulletin 124; page 110.

TABLE IV.—FERTILIZERS ON CROPS GROWN IN ROTATION.

Value of increase per acre in 5-crop rotation.

PLOT No.	WOOSTER:—9-year average.					STRONGSVILLE:—7-year average.				
	Corn	Oats	Wheat	Hay	Total	Corn	Oats	Wheat	Hay	Total
2	$2.37	$ 2.07	$ 5.33	$ 1.63	$11.40	$ 2.64	$ 2.77	$ 5.23	$ 3.92	$14.56
3	1.61	.49	1.14	1.20	4.44	.26	.43	—.34	.18	.53
5	1.49	1.15	1.12	1.88	5.64	.23	.26	—.36	.44	.57
6	4.88	4.01	8.59	4.57	22.05	3.01	3.69	6.86	3.20	16.76
8	4.20	2.86	6.78	2.73	16.57	2.37	3.13	4.85	4.00	14.35
9	1.74	1.05	1.51	1.94	6.24	.31	.64	1.09	.46	2.50
11	5.80	5.29	11.20	5.54	27.83	4.19	3.74	7.09	4.96	19.98
12	6.18	5.49	11.88	5.42	28.97	3.36	3.53	9.66	3.78	20.33
14	5.62	2.20	9.86	5.02	22.70	2.76	1.66	8.18	4.42	17.02
15	2.55	.87	9.29	2.86	15.57	.97	.25	6.81	2.19	10.22
18	5.67	2.63	5.94	7.39	21.63	4.01	2.15	6.64	5.07	17.82
20	3.96	1.50	3.88	5.22	14.56	2.59	.74	3.87	4.23	11.43

TABLE V.—COST OF FERTILIZERS AND PROFIT OR LOSS PER ACRE.

Plot No.	Cost of fertilizers.				Profit (+) or loss (—) per acre.							
					At Wooster.				At Strongsville.			
	On corn	On oats	On wheat	Total for 5 years	On corn	On oats	On wheat	Total for 5 years	On corn	On oats	On wheat	Total for 5 years
2	$0.60	$0.60	$1.20	$ 2.40	$+1.77	$+1.47	$+4.13	$+9.00	$+2.04	$+2.17	$+4.03	$+12.16
3	2.00	2.00	2.50	6.50	—0.39	—1.51	—1.36	—2.06	—1.74	—1.57	—2.84	—5.97
5	4.00	4.00	4.00	12.00	—2.51	—2.85	—2.88	—6.36	—3.77	—3.74	—4.36	—11.43
6	4.60	4.60	5.20	14.40	+ .28	—0.59	+3.39	+7.65	—1.59	—0.91	+1.66	+2.36
8	2.60	2.60	3.70	8.90	+1.60	+0.26	+3.08	+7.67	—0.23	+0.53	+1.15	+5.45
9	6.00	6.00	6.50	18.50	—4.26	—4.95	—4.99	—12.26	—5.69	—5.36	—5.41	—16.00
11	6.60	6.60	7.70	20.90	—0.80	—1.31	+3.50	+6.93	—2.41	—2.86	— .61	—0.92
12	8.60	8.60	9.70	26.90	—2.42	—3.11	+2.18	+2.07	—5.24	—5.07	— .04	—6.57
14	6.60	...	7.70	14.30	—0.98	....	+2.16	+8.40	—3.84	....	+ .48	+2.72
15	....	....	7.70	7.70	....	....	+1.53	+7.87	....	....	— .89	+2.52

The oats crop shows much the same behavior towards the separate fertilizing materials as the corn crop; the increase from the acid phosphate alone showing a handsome profit and that from acid phosphate and muriate of potash covering cost of fertilizers, but in no case has a nitrogenous fertilizer produced sufficient increase of oats to pay for its cost.

In the case of the wheat crop, acid phosphate has thus far been used at a profit at Wooster in every case, and at Strongsville in most cases, notwithstanding the fact that the quantity used on wheat has been equal to that used on corn and oats combined. The nitrogenous fertilizers have also given a relatively better financial return on wheat than on corn or oats. Even the very expensive application on plot 12 shows a considerable profit at Wooster, and is practically recovered in the increase at Strongsville, whereas it is used with apparent loss on both corn and oats.

Table III shows that the superior value of the increase of wheat is chiefly due to the higher value of the crop per bushel, for there have been in most cases as many or even more bushels of increase in the corn crop than in the wheat. If, however, we compare the increase of the two crops on the basis of percentage of the unfertilized yield we shall find that the wheat increase has been proportionally very much the greater.

Taking the table as a whole we find that, at the prices at which the crops and fertilizers respectively have been computed, the only artificial fertilizer which has returned a net profit on all the crops in both tests has been the very small dressing of acid phosphate applied to plot 2. This has brought an increase sufficient to pay its cost several times over on each crop, besides producing a very considerable residual increase in the hay crops, the total gross increase per acre from 320 pounds of acid phosphate, distributed over the three cereal crops in a 5-year rotation, amounting to $11.40 per acre at Wooster and $14.56 per acre at Strongsville; the net increase, after deducting the cost of the fertilizer, being $9.00 per acre at Wooster and $12.16 at Strongsville.

Muriate of potash and nitrate of soda, when used either separately, or combined with each other, but not with acid phosphate, have in no case produced sufficient increase of crop to cover their cost, in the quantities used in these tests. It does not follow, however, that the fertilizer may wisely be limited to acid phosphate alone, for the very large additional increase which these materials produce, when combined with acid phosphate, shows that both nitrogen and potassium are needed in the fertilizer if the highest effect is to be attained; the problem being to determine in what proportions to phosphorus these elements may be used with greatest economy.

Even at Strongsville, where the relative effect of acid phosphate is greater, there still seems to be room for the use of both nitrogen and potassium, as is seen by comparing the yields of plots 2, 6 and 11. These plots receive exactly the same quantities of acid phosphate, but plot 6 receives nitrogen in addition, and plot 11 both nitrogen and potassium.

While the tables show that neither the corn nor the oats crop has usually paid for the fertilizers applied directly to those crops in these tests, yet it does not follow that the fertilizing of the corn and oats crops has been altogether unprofitable, so far at least as the corn crop is concerned. An inspection of the columns showing values of hay increase shows that a very considerable part of the total effect from the fertilizers is being found in the hay crop, while the increase of corn on plot 15, and of oats on plot 14, also shows that there is continually a reaching over of the effect of a fertilizer from one crop to those following.

At the present stage of the work at Wooster, plot 14 shows a slightly larger net increase than any other one in the series except plot 2, but at Strongsville no other plot as yet approaches the net increase found on plot 2, receiving acid phosphate only. While the increase in the corn crop found on plot 14 is not alone sufficient to pay the cost of the fertilizer applied to that crop, yet when the residual effect of this application, as gleaned by the oats crop following, is added to that found in the corn crop the total is sufficient to give a considerable margin of profit at Wooster, though still a deficit at Strongsville. In this connection it is interesting to note that at Wooster the effect of the fertilizers is steadily increasing, as shown in Table VI, which gives the average total value of the increase from the differently fertilized plots for the periods given. It will be understood that each column in this table shows the average results for the entire period of the experiment, up to and including the year heading the column, thus showing that each year's increase has been sufficiently large to materially raise the level of the entire period preceding. Under the plan of this experiment it will be remembered that each year's work completes an entire rotation, each of the five crops being represented each year.

TABLE VI.—AVERAGE VALUE OF TOTAL INCREASE IN 5-CROP ROTATION AT WOOSTER.

Plot Number.	5 years ending 1898	6 years ending 1899	7 years ending 1900	8 years ending 1901	9 years ending 1902
2	$ 6.93	$ 7.41	$ 9.39	$10.68	$11.40
3	3.88	4.08	4.12	4.30	4.44
5	4.26	4.56	4.60	5.00	5.64
6	16.90	17.92	20.92	20.44	22.05
8	12.64	13.47	14.83	16.16	16.57
9	5.25	5.22	5.06	5.52	6.24
11	21.85	24.66	23.46	26.24	27.82
12	21.61	23.75	25.05	26.85	28.97
14	17.98	18.81	19.74	21.44	22.70
15	10.93	13.12	14.89	14.66	15.58
Average of fertilized plots	**12.22**	**13.30**	**14.21**	**15.13**	**16.14**
18	17.95	17.18	19.96	20.94	21.63
20	12.55	12.56	13.14	14.12	14.53
Value of total yield of unfertilized plots	**42.94**	**42.18**	**41.17**	**41.76**	**42.75**

Table VI shows that the rate of gain has been larger on the plots most liberally fertilized or manured, and that these plots are gradually outranking the others in net profit per acre. That this increase has been actual, and not merely due to a dimished yield on the unfertilized land, is shown by the last line of the table, which shows that the unfertilized yield is remaining practically stationary. The Strongsville test, however, does not yet manifest this tendency toward increasing yield.

These results suggest the inquiry whether the quantities of nitrogen and potassium may not be considerably reduced without causing a corresponding reduction in the increase of the crop. This question is being studied in the Strongsville test, in which on plots 32 and 33 the muriate of potash is reduced to one-half and one-fourth the quantities used on plot 11, and on plots 35 and 36 the nitrate of soda is similarly reduced. Table VII gives the distribution of fertilizers in this test and the total value of increase, as compared with plot 11.

These results would seem to justify the inference that for this soil, in its present condition, both nitrogen and potassium may be reduced to the lowest quantities employed on these plots without material reduction of effect. This would give a fertilizer carrying about 4 percent nitrogen, 10 percent phosphoric acid and 6 percent potash, weighing 500 pounds and costing $7.00 in total for the three crops.

TABLE VII.—EFFECT OF REDUCTION OF NITROGEN AND POTASSIUM.

Plot No.	Fertilizers per acre in 5 years. Acid phosphate	Muriate of potash	Nitrate of soda and dried blood	Total cost of fertilizers	Total value of increase	Net profit (+) or loss (—)
	Pounds.	Pounds.	Pounds.			
11	320	260	490	$20.90	$19.98	$—0.92
32	320	260	245	14.90	19.10	+4.20
33	320	260	125	11.90	19.39	+7.49
35	320	130	490	17.65	18.10	+0.45
36	320	65	490	16.05	20.15	+3.90

Whether the time may come when a larger proportion of nitrogen and potassium may be required in the fertilizer, remains for future years to determine.

Additional light is thrown upon this question by still another experiment at Strongsville, in which, on 4 plots, Nos. 3, 6, 9 and 13, tankage, acid phosphate and muriate of potash are mixed in varying proportions to give fertilizers having the percentage composition shown in Table VIII, and on two plots, Nos. 15 and 16, raw and steamed bone meal are used, the fertilizers all being applied in the uniform quantity of 200 pounds per acre to corn and wheat, which are grown with clover in a 3-year rotation. Six crops of corn have thus far been harvested in this test and 4 crops each of wheat and hay, one crop of wheat having been destroyed by the severe winter of 1898-99. Table VIII gives the composition and cost of fertilizers, and the total and net values of increase, as found in this test.

TABLE VIII.—COMPARISON OF FERTILIZERS OF DIFFERENT PERCENTAGE COMPOSITION.

Plot No.	Percentage composition of fertilizers. Nitrogen	Total phosphoric acid	Potash	Total cost of fertilizers	Total value of increase	Net profit
3	3⅓	12¼	3¾	$4.32	$14.77	$10.45
6	1⅔	14⅓	1¼	3.68	19.20	15.52
9	2	10½	1¼	3.10	10.41	7.31
13	1	7⅓	1¼	2.05	10.05	8.00
15	4	24	...	5.20	17.43	12.23
16	3	27	...	4.80	19.90	15.10

This table is in harmony with those which precede it in showing that phosphorus is the dominant element of the fertilizer in producing increase of crop on this soil. Comparing plots 3 and 6 it appears that the reduction of nitrogen and potash has been more than compensated by increase of phosphoric acid, and comparing plots 6 and 13 we see that the increase is approximately proportioned to the quantity of phosphoric acid. It will be observed that the largest total increase thus far found in this test is that shown on plot 16, which receives no potash. This plot may be compared with plot 6 in the 5-year rotation, but in making this comparison we must remember that the fertilizers are applied 2 years out of 3 in the shorter rotation and 3 years out of 5 in the longer one. Considering only the nitrogen and phosphoric acid carried in the fertilizers we find that the fertilizing in the shorter rotation is equivalent to an annual dressing of 4 pounds of nitrogen and 36 pounds of phosphoric acid, and in the longer one to 25 pounds of nitrogen and 10 pounds of phosphoric acid, while the total value of the increase is equivalent to an annual value of $6.65 in the shorter rotation as against $3.25 in the longer one.

Remembering that the comparison of plots 2 and 6 in the longer rotation demonstrates the need of some nitrogen, it is evident that, with frequent culture of nitrogen gathering crops, and on a soil which has not been depleted of its humus by exhaustive cropping, the proportion of nitrogen to phosphoric acid in the fertilizer may well be much smaller than that used in the fertilizing of the longer rotation in these experiments; but the progressive increase in the effect of the highly nitrogenous fertilizers on the depleted soil at Wooster shows that the time may come when large applications of fertilizer nitrogen may be required.

Remembering also that the comparison of plots 6 and 11 in the longer rotation has shown that, after both nitrogen and phosphorus have been supplied, then the addition of a carrier of potassium produces a further increase of crop, we may logically infer that a small addition of such a carrier would have increased the effectiveness of the bone meal in the shorter rotation, an inference justified by a comparison of the plots receiving bone meal with those receiving the complete fertilizer, a comparison which demonstrates that phosphorus and nitrogen have not been the only constituents determining the effectiveness of the fertilizer.

Attention is called to the superior effect of the steamed bone meal, as compared with the raw bone meal on plots 15 and 16 of the shorter rotation. This superiority is doubtless chiefly due to the greater fineness of the steamed meal. In our analysis 23 percent of the steamed bone meal was classed as "fine" as against 17 percent of the raw meal.

EFFECT OF FERTILIZERS AND LIME UPON CLOVER.

In the long rotation upon the depleted soil at Wooster it is becoming more and more difficult to secure a crop of clover. The seed germinates and a stand is usually secured, but the growth is weak and by the second season if not earlier the clover has disappeared. In the spring of 1900 an experiment was begun with the object of testing the effect of lime upon this soil. In this experiment one half of each section of the 5-year rotation is dressed with lime after the land is prepared for corn, the lime being used in the form of ground, unslacked lime, applied at the rate of 1000 pounds per acre, and distributed evenly across the plots, so that one half of each plot is limed and the other half is left without lime.

This work was begun on section E. The corn, oats and wheat crops, following the liming, each gave a larger average yield on the limed, than on the unlimed ends of the plots, although the rate of increase was not uniform and there was a slight decrease on a few of the plots. The first clover crop in this test was sown on the wheat harvested in 1902. Soon after the wheat was taken off it became apparent that a much better stand of clover had been secured on the limed half of the section than on the other, and this superiority has been maintained.

Table IX gives the yield and increase of hay found on the two ends of each plot in 1903, the plots being grouped according to method of treatment. This hay crop consists of clover and timothy, with some weeds, chiefly white top. It will be observed that every unfertilized plot, except No. 28, shows a larger yield on the limed, than on the unlimed half, the differences being in most cases quite decided.

In the case of plots treated with incomplete fertilizers (Nos. 2, 3, 5, 6, 8, 9) the limed end has invariably shown a much larger yield than the unlimed end; but, it is noticeable that where the fertilizer has carried nitrogen in nitrate of soda there has been less difference in the rate of increase than where nitrogen is omitted.

Seven plots, Nos. 11, 12, 17, 21, 23, 24 and 30, receive complete fertilizers containing equal quantities of phosphoric acid and potash, carried in acid phosphate and muriate of potash except on plot 30, where

TABLE IX.—EFFECT OF LIME UPON CLOVER.

Yield and increase in pounds per acre.

TREATMENT	Plot No.	Yield		Increase (or decrease —)	
		Limed	Unlimed	Limed	Unlimed
Unfertilized	1	1714	958	....	...
	4	1754	830	....	....
	7	1431	894	....	....
	10	1089	639	....	....
	13	1250	936	....	....
	16	1109	1064	....	....
	19	1512	1000	....	....
	22	1129	617	....	....
	25	1149	702	....	....
	28	847	894	....	....
	Av.	1298	853		
Incomplete fertilizers..........	2	2319	809	592	—106
	3	1613	851	—28	—21
	5	2157	1362	511	511
	6	2964	1702	1425	829
	8	2339	894	1022	85
	9	1250	1000	47	277
	Av.	2107	1103		
Complete fertilizers, with different carriers of nitrogen:...	11	2540	2255	1397	1517
	12	3024	2425	1828	1587
	17	3226	2425	1983	1382
	21	2339	1149	1082	404
	23	2258	1042	1122	397
	24	2258	1000	1116	326
	30	2339	1957	1492	1163
	Av.	2569	1750		
Complete fertilizers, with different carriers of phosphoric acid........................	11	2540	2255	1397	1517
	26	2560	2340	1512	1574
	27	1754	1830	806	1000
	29	1875	2277	1028	1328
Barnyard manure.............	18	3810	2745	2432	1724
	20	2460	1553	1076	681
	Av.	3133	2149		

half the phosphoric acid is given in tankage, but with nitrogen either in varying quantities or in different carriers. Nos. 11, 12 and 17 receive respectively 75,113 and 38 pounds of nitrogen during each 5-year rotation, carried in nitrate of soda, while Nos. 21, 23, 24 and 30 get 38 pounds, carried respectively in linseed oil meal, dried blood, sulphate of ammonia and tankage. For this season and crop nitrate of soda appears to have been a more effective carrier of nitrogen than either of the other materials, but the general average of all the work for 10 years past would show a considerably smaller difference than is here indicated. All these plots show a larger yield on the limed than on the unlimed half, and all except No. 11 show a larger increase on the limed half. In the case of No. 11 the stand of clover was distinctly better on the limed half than on the other, but a relatively larger growth of timothy on the unlimed end caused that end to show a somewhat greater rate of increase.

Four plots, Nos. 11, 26, 27 and 29 receive the same quantities of nitrogen in nitrate of soda (except that on plot 26 allowance is made for the nitrogen carried in bone meal) with equivalent quantities of phosphoric acid, carried respectively in acid phosphate, raw bone meal, dissolved bone black,and slag phosphate. The three plots treated with non-acidulated phosphate —Nos 26, 27 and 29—show a more uniform stand of clover over both ends than any other in the series,although the total yields of hay were smaller in the case of Nos. 27 and 29 than in some other cases. This was apparently due in part to greater poverty of the soil at this end of the field,as indicated by the yield on plot 28. This end of the section is in fact much higher than the opposite end, and the yield of the unfertilized plots shows a general though irregular decrease from plots 1 to 28.

Finally, 2 plots, Nos. 18 and 20, receive barnyard manure, at the rate of 8 tons per acre on the corn and wheat crops on plot 18, or 16 tons for each 5-year rotation, and half that quantity on plot 20. These plots show an average yield nearly half a ton per acre greater on the limed than on the unlimed ends, while their rate of increase is also much greater on the limed ends.

Nothing has been more clearly demonstrated than the danger of jumping at conclusions in field experiments. The processes by which plant food is elaborated in the soil are so complex and the effect of seasonal conditions so great that a cycle of observations must be made before we can venture upon more than general conclusions. This much, however, seems to be demonstrated by the work above described, and which is apparently being supported by the section in the same test which was limed for the corn crop of 1901 and from which the wheat has just been cut, namely: that on a soil which has become acid through exhaustive cultivation and the use of incomplete fertilizers, and on which clover refuses to grow, the addition of lime may restore the conditions essential to clover production.

THE HOME MIXING OF FERTILIZERS.*

The experiments of this Station have demonstrated beyond question that the farmer may mix his own fertilizers from tankage, acid phosphate and muriate of potash at a considerable saving in cost and without any loss in effectiveness. For this purpose what is known as "7 and 30" tankage is probably the most suitable; that is, one containing 7 percent "ammonia" and 30 percent "bone phosphate," bone phosphate being a combination of phosphoric acid and lime in the proportion of about 46 percent of the former to 54 percent of the latter. A 7 and 30 tankage would therefore contain about 13 percent of phosphoric acid, which would probably be in about the same condition of availability as that in the steamed bone meal used in our experiments. Ground tankage should be

TABLE X.—FORMULÆ FOR HOME MIXING OF FERTILIZERS.

Formula	Materials		Composition			Cost
	Kind	Quantity	Ammonia	Phosphoric Acid	Potash	
		Pounds	Pounds	Pounds	Pounds	
A	Tankage (7-30)	300	21	39		$ 3.75
	Acid phosphate	1620	..	226		12.15
	Muriate of potash	80	..	....	40	2.40
	Total	2000	21	265	40	18.30
	Percentage composition		1	13	2	
B	Tankage (7-30)	900	63	117	..	11.25
	Acid phosphate	980	..	137	..	7.35
	Muriate of potash	120	..	....	60	3.60
	Total	2000	63	254	60	22.20
	Percentage composition		3.1	12.7	3.	
C	Tankage (7-30)	1200	84	15.6	..	15.00
	Acid phosphate	640	..	89	..	4.80
	Muriate of potash	160	..	..	80	4.80
	Total	2000	84	245	80	24.60
	Percentage composition		4.2	12.2	4.	
D	Tankage (7-30)	1720	120	223	...	21.50
	Acid phosphate	40	...	5	...	.30
	Muriate of potash	240	...	...	120	7.20
	Total	2000	120	228	120	29.00
	Percentage composition		6	11.4	6	

*This subject is more fully treated in Bulletin 100 of this Station.

called for, and may be bought of western slaughter houses at prices which bring the cost of the grade mentioned to about $25 per ton at retail, delivered at Ohio points. Acid phosphate, analyzing 14 percent phosphoric acid and over, may be bought of local dealers at $14 to $15 per ton or less; muriate of potash, analyzing 50 percent actual potash, may be bought in small lots in New York and freight paid to Ohio at a total cost below 3 cents per pound.

The tankage and acid phosphate are fine powders and the muriate of potash is a coarse salt. They require no further treatment and are readily mixed into the condition in which they are found in the branded fertilizer sack. They are, in fact, the identical materials of which the professional fertilizer mixers make their various compounds. In Table X are given a few sample formulæ, showing how a fertilizer of almost any desired composition may be made.*

CONCLUSIONS.

The experiments herein reported have been made upon a thin sheet of glacial drift, lying upon and largely modified by shales and sandstones of the Waverly formation. They have been in progress for from 6 to 10 years, and the more evident conclusions which they indicate may safely be accepted as applying to the broad

*Nitrogen, phosphorus and potassium are not available as food for the higher plants in their elementary condition, but must first enter into combination with oxygen, and in the case of nitrogen and phosphorus this combination is recombined with some other substance before the materials take on a commercial form. Nitrogen, combined with a definite proportion of hydrogen becomes ammonia; ammonia unites with oxygen, forming nitric acid, and nitric acid combines with soda, lime, potash, etc., giving us nitrate of soda, nitrate of lime, nitrate of potash, etc. The carriers of nitrogen in ordinary use are (1) slaughter-house refuse (dried blood, tankage, bone meal, etc.,) in which form the nitrogen is termed organic nitrogen, and from which it is converted into nitrate nitrogen in the soil; (2) sulphate of ammonia and (3) nitrate of soda, the last named being the most valuable, as the nitrogen is already in the nitrate condition.

Phosphorus combines with oxygen, producing phosphoric acid, and this, when united with lime, gives phosphate of lime, the chief constituent of bones. Natural deposits of phosphate of lime are found in our southern states, which is ground into powder and treated with sulphuric acid, producing the acid phosphate of the fertilizer trade. The object of this treatment is to increase the solubility of the phosphate rock.

Potash is the name given to a combination of potassium with oxygen. The ordinary carriers of potassium used for fertilizing purposes are muriate of potash, in which the potash is combined with muriatic acid; sulphate of potash, in which the potash is combined with sulphuric acid, and kainit, which is a crude salt, consisting chiefly of a mtxture of muriates (or chlorides) of potash and soda, muriate of soda (or sodium chloride) being common salt.

In the fertilizer trade it has become customary to use the terms ammonia, phosphoric acid and potash, instead of nitrogen, phosphorus and potassium, which are the essential constituents of the fertilizer.

belt of this formation which extends throughout the middle of the state from north to south. Whether they may be as safely accepted on the limestone areas of the state remains yet to be determined. These conclusions are as follows:

1. For the soils under test in these experiments phosphorus is the controlling element in producing increase of cereal crops, and neither nitrogen nor potassium will produce a profitable increase except when used in association with phosphorus.

2. Except on soils which have been depleted by exhaustive cropping the quantity of phosphorus in the fertilizer, as compared with the nitrogen and potassium, should be much greater than that found in barnyard manure.

3. While the effect of nitrogen in the fertilizer is secondary to that of phosphorus on these crops grown in rotation with clover, the considerably larger increase produced by fertilizers containing nitrogen, especially in the wheat crop on the worn soil at Wooster, is evidence that this element cannot be entirely omitted from a fertilizer for such soils without loss of possible increase.

4. Potassium apparently occupies the third place, in a fertilizer for these soils, yet it is evident that some carrier of this element is essential to the highest effectiveness of the fertilizer.

5. No definite ratio between the different constituents of the fertilizer can be fixed for all soils and crops. Apparently, crops immediately succeeding clover or other legumes require less nitrogen in the fertilizer than those more remote, while the ratio between the phosphorus and potassium needed is probably chiefly determined by the geological history of the soil.

For soils similar in character to those used in these experiments we suggest the following fertilizer formulæ, as being approximately indicated by the results of our own experiments to date, holding these suggestions open to change with the progress of our work:

TABLE XI.—FERTILIZERS SUGGESTED FOR DIFFERENT CONDITIONS.

Conditions.	Percentage composition.		
	Ammonia	Phosphoric Acid	Potash
For crops immediately following clover	1	13	2
For crops 1 or 2 years after clover	3	12	3
For crops 2 or 3 years after clover	4	12	4
For crops on exhausted soils	6	11	6

EXPLANATION OF PLATES

The accompanying photo engravings are views of parts of Section E, 5-year rotation, taken in June, 1903.

Plate I is a view of the unlimed half, looking south across the plots. Plot 1, unfertilized, is in the immediate foreground, and shows considerable clover; in fact, most of the unfertilized plots show comparatively little difference in clover growth between the limed and unlimed ends, and all show more clover than is found on the unlimed ends of the partially fertilized plots which had received no nitrogen, Nos. 2, 3 and 8. The failure of the clover beyond Plot 1 is plainly shown.

Plate II is a similar view of the limed half of the section.

Plate III is a view of the unlimed end of plot 2, fertilized only with acid phosphate, looking eastward. This view shows a narrow streak of clover along the right-hand side, separating plots 2 and 3. This clover grew in the two-foot dividing space between the plots, which had received no fertilizer.

Plate IV is a view of the same plot, looking westward over the limed half.

Plates II and IV show more or less "white-top" (*Erigeron annuus*) but the clover beneath is easily distinguishable.

PLATE I.

PLATE II.

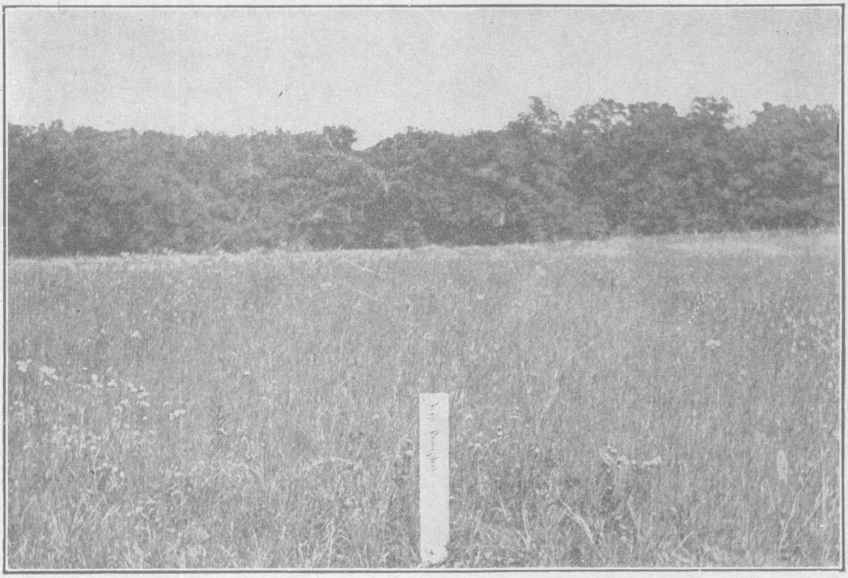

PLATE III.

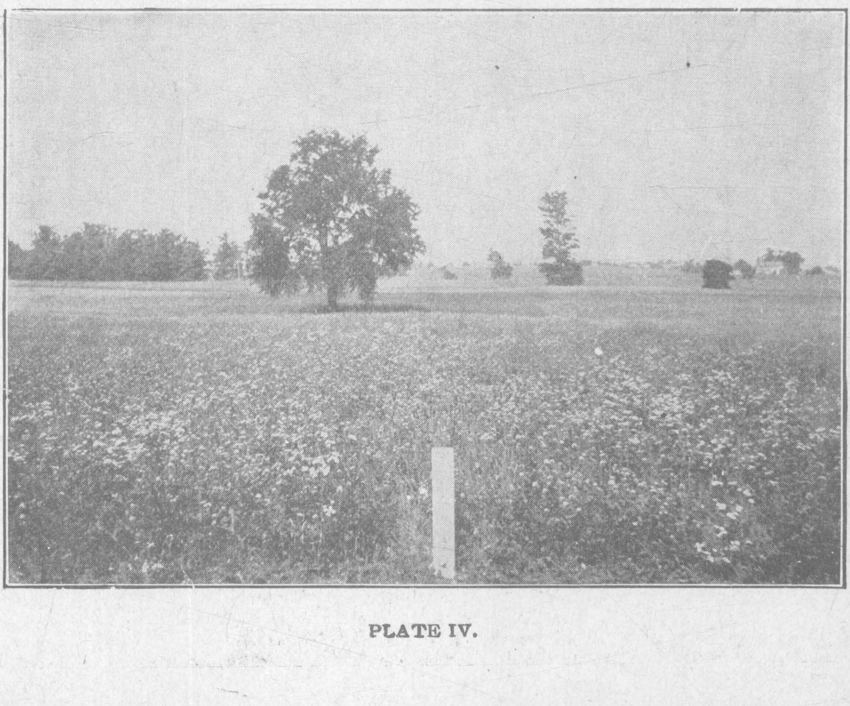

PLATE IV.